Circular No. 839

March 1950 • Washington, D. C.

UNITED STATES DEPARTMENT OF AGRICULTURE

Mechanical Drying of Corn on the Farm[1]

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WHY THERE IS INTEREST IN MECHANICAL DRYING

There is a generally recognized need for improvement in grain-storage methods on farms. No comprehensive statistics have been obtained on the extent of damage to grain in storage, but it is known that severe losses occur. In each 10-year period we may expect in some areas in the Corn Belt 4 or 5 years during which a large quantity of corn will be severely damaged because it is not dry enough to prevent molding in storage. A good many farmers and country elevator operators have expressed the opinion that the increase in high-moisture corn in recent years was caused by the use of hybrid seed. It has not been shown that hybrid corn has any inherent high-moisture characteristic, but it is true that the development of a large number of hybrids has given the farmer a wide choice of maturity dates.

The farmer has dozens of hybrids to choose from and unfortunately the high-yielding hybrids are generally those that require a long growing season. He has a tendency to take some risk in choosing a high-

[1] Report of a study made under the Research and Marketing Act of 1946 by the Bureau of Plant Industry, Soils, and Agricultural Engineering of the Agricultural Research Administration, the Grain Branch of the Production and Marketing Administration, and the Extension Service, United States Department of Agriculture, in cooperation with the agricultural experiment stations of Iowa, Illinois, Indiana, Ohio, and Michigan.

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yielding hybrid; then, if planting is delayed by wet weather or the summer is cool or there is not good drying weather in the fall, he may have the problem of storing corn that is not dry enough for ordinary crib storage.

Storage difficulties have been increased by the development of mechanical pickers for harvesting corn. Mechanical pickers often do not husk the corn so clean as hand huskers do. Shelled corn and husks mixed with the ears tend to retard air movement through corn in cribs and thus prevent proper curing. When corn pickers are used, particularly on a custom basis, there is a tendency to go ahead with the harvest at times when the corn is not quite dry enough for safe storage. These difficulties were accentuated during the 4 years 1944–47, when crop and weather conditions were unfavorable for corn storage in some areas in the Corn Belt and when grains were scarce and high in price. As a result, there is a demand for some method of crop conditioning that will be more nearly independent of weather. Mechanical drying, that is, forced ventilation of the grain with either heated or unheated air, is a possible answer.

METHODS OF UTILIZING HIGH-MOISTURE CORN

The general recommendations on methods of utilizing, handling, and storing soft or high-moisture corn are well known to farmers in the Corn Belt. These recommendations include such practices [2] as:

1. Ensiling both fodder and shelled corn.
2. Sorting and early feeding of soft corn to hogs or other livestock.
3. Delayed harvesting to allow maximum drying of ear corn in the field.
4. Clean husking to eliminate trash that reduces ventilation in the crib.
5. Using screens on the elevator to screen out shelled corn, silks, or other material.
6. Good distribution in the crib to avoid pockets of shelled corn and debris where spoilage is most likely to start.
7. Storing corn of highest moisture content in the narrowest cribs to facilitate natural ventilation.
8. Using adequate ventilators in cribs.

It may be assumed that farmers have adopted these recommendations as far as seemed practicable with existing structures and available materials and labor. Grain-storage results, however, have not been entirely satisfactory. The grain-storage research work of the United States Department of Agriculture carried on in cooperation with State agricultural experiment stations included numerous observations of storage of ear corn in farm cribs during the years from 1937 to 1945. In each crib under observation probe samples were obtained for moisture and damage determinations in the winter and again late in the spring or in the summer. Observations were made in a total of 516 cribs in Indiana, Illinois, Iowa, Nebraska, and Minnesota: No. 1, 2, or 3 corn was produced in 361 of these cribs, No. 4 or 5 corn in 76 cribs, and sample-grade corn in 79 cribs. These grade designations were

[2] Detailed information on these practices is given in Farmers' Bulletin 1976, Handling and Storing Soft Corn on the Farm, and in bulletins of the State agricultural colleges.

based on damage only, other grade factors being neglected. The sample-grade corn varied in different cribs from slightly over 15 percent to as much as 90 percent damaged kernels.

DRYING EAR CORN

The use of forced ventilation with either heated or unheated air for drying corn is new to most farmers, although drying with heated air has been used for a number of years by producers of hybrid seed corn. Recent development of small portable driers has made it possible for farmers to use this method of curing the corn crop.

Some advantages of mechanical drying are as follows:

1. The curing of the crop is almost independent of weather, especially when heated air is used.
2. The corn can be dried and storage losses avoided in "wet-corn" years.
3. The corn can be harvested earlier in the fall when mechanical pickers will do a better job of husking. Under ordinary conditions they will save perhaps 2 bushels or more per acre that they will lose in the field if harvest is delayed until the corn is dry enough for safe storage. Storms accompanied by high wind after November 1 may blow down many cornstalks and blow many ears off the stalks. After such storms field losses with mechanical pickers will be excessive, but even without a severe storm the saving in field losses will, at least partially, offset the cost of mechanical drying. Later harvesting will be more costly because of shorter days and the probability of muddy, snow-covered, or frozen ground. Furthermore, an early harvest permits preparation of a field for seeding wheat or other fall-planted crops and fall plowing when desired.
4. The corn can be stored in a tight bin where it can be fumigated to control insects.
5. Crib space can be saved by drying the corn, shelling and storing it elsewhere as shelled corn, and then filling the crib again.
6. Eliminated are loss in weight of dry matter of corn and losses in nutritive value due to insects and molds, market discounts for high moisture and damage, and the problem of utilizing moldy corn for livestock feed.

Some disadvantages of mechanical drying are as follows:

1. Extra labor is necessary and cost of drying, including the investment in equipment and the extra fire hazard when heat is used, must be considered.
2. Market premiums for dry corn may not compensate for loss in weight if corn to be sold is dried below 15½ percent average moisture content.

Filling and Preparation of Cribs for Mechanical Drying

Most farm cribs can be prepared for mechanical drying after they have been filled. There are some exceptions. For example, most of the different types of ventilators used in cribs will interfere with good forced-air distribution and they should be blocked or removed before the crib is filled.

Clean preparation of the corn is just as important for mechanical as for natural drying. Air flow will tend to bypass any pocket where

there is an accumulation of shelled corn, husks, and debris. The corn should be husked as clean as possible. A screen should be used in the elevator to take out shelled corn, chaff, and dirt. *Unless the elevator drops the corn on a spreading device in the crib, the elevator spout should be moved frequently and directed so that shelled corn and debris will be deposited near the outside wall rather than in the middle of the crib.*

DISTRIBUTION OF AIR

The air must enter and leave the crib in such a way that it travels about the same distance through the corn in all parts of the crib. In a crib without ventilators, this can be accomplished by covering the lower part of one side of the crib with a large canvas tarpaulin attached with enough slack to allow it to balloon out from the crib wall and form a duct into which air is blown. When a canvas tarpaulin is not available, the duct along the side of the crib can be built with reinforced kraft paper supported on a light framework. The size of the duct should be at least *1 square foot* cross section for each *1,000 cubic feet per minute* of air delivered by the blower. The crib wall above the duct and the ends of the crib are sealed by covering with canvas or with reinforced kraft paper. From the duct the air passes through the corn to the top surface or to the opposite side of the crib. This arrangement is shown in figure 1.

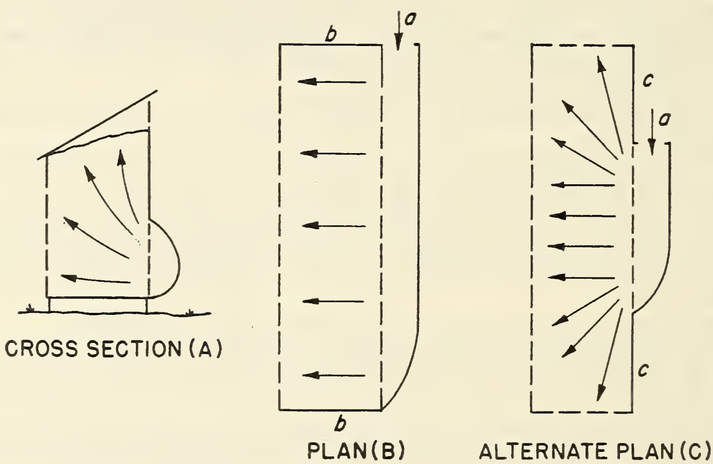

FIGURE 1.—Preparation of a frame single crib for ventilation. Cross section (*A*) with floor plan (*B*) and alternate floor plan (*C*) shown. End walls of crib should be covered as shown at *b* or side walls as shown at *c*. Plan (*B*) is recommended over alternate plan (*C*). A double crib can be prepared in this manner when it is desired to dry only one crib at a time. Air blown in at *a* will escape through the crib as indicated by arrows.

The preparation of a frame crib for ventilation when the depth of corn and the width of the crib are of similar dimensions is shown in figure 2.

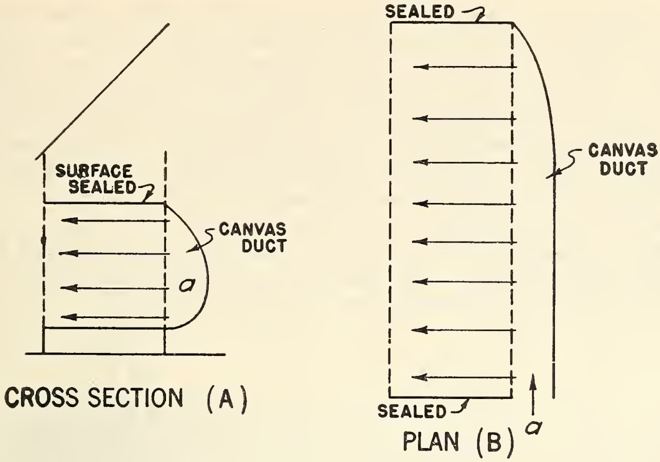

FIGURE 2.—Preparation of frame crib for drying where depth of corn and width of crib are of similar dimensions. Corn surface is sealed and air moves horizontally through the corn. Air enters canvas duct at *a*.

In the preparation of a frame double crib for ventilation as shown in figure 3 both driveway doors are closed and sealed with reinforced paper. Air blown into the driveway at *a* escapes through the crib as indicated by arrows. The covering of end walls as at *d* is recommended; however, an alternate plan, not as good, is to cover driveway walls back 6 to 8 feet from the end, as at *e*. *Distance of air path to surface of corn at all points should about equal the crib width,* but allow-

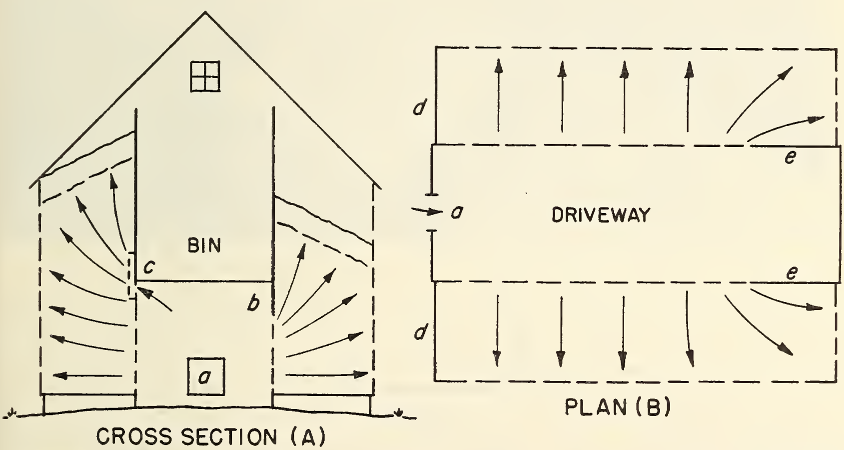

FIGURE 3.—Preparation of a frame double crib for ventilation. Cross section (*A*) and floor plan (*B*) are shown.

ance should be made for settling (2 to 3 feet in high cribs) as the corn dries. If the height of the settled corn above the bin floor is less than the crib width, the upper part of the driveway wall at *b* should be covered. If the height of settled corn above the bin floor is greater than the crib width, slats should be used on the back of bin studs at *c* to keep the air passage open to a level that will equalize the air path through the corn. If the bin walls are slatted to the top of the crib on the back of the studs as well as on the front, it will be necessary, in order to prevent short circuiting of air, to remove slats or to close stud spaces at proper level when covering the upper part of the wall. Windows should be kept open while the corn is being dried.

Other arrangements are shown in figures 4 and 5.

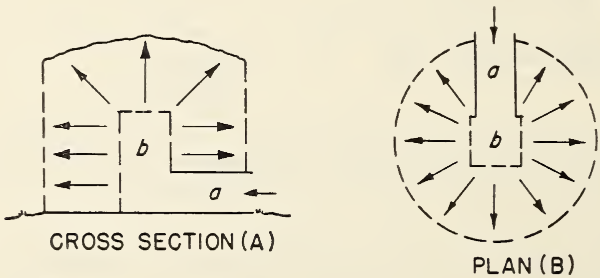

FIGURE 4.—Cross section and plan of a round snow-fence crib, showing preparation for forced ventilation. Intake duct at *a* should be airtight. Air blown into ventilator at *b* escapes through the corn as shown.

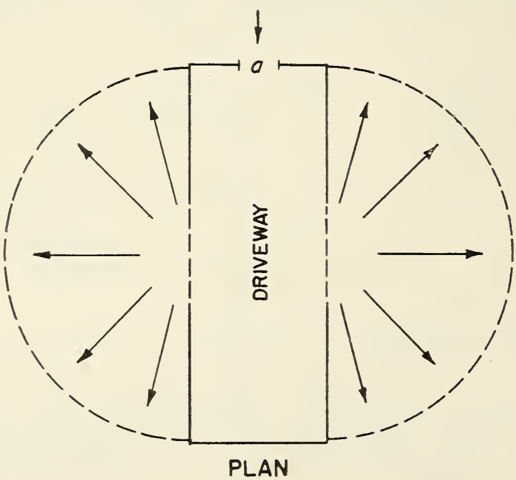

FIGURE 5.—Preparation of a concrete-stave crib for ventilation. Walls of driveway should be covered as shown and openings, such as those around inside elevator or ladderway, should be sealed. Air blown into driveway at *a* will then escape through the corn as shown.

A false floor developed for drying ear corn and small grain in steel bins is shown in figure 6. The drier is attached to the entrance duct shown at the door. The drying air, blown under the perforated false floor, passes vertically through the corn and out of the top of the bin. Mechanical unloading can be accomplished by placing a drag conveyer underneath and taking out the removable boards shown in the center of the bin. The perforated floor consists of hardware cloth resting on 2- by 4-inch joists spaced 6 inches apart and supported by rows of concrete blocks laid with the flat side down so that air can circulate through them, the rows spaced 3 feet apart. On the concrete blocks 2- by 8-inch planks are laid flat to give good bearing for the 2 by 4's. Perforated metal or expanded metal laid flat can be used for the floor instead of hardware cloth. If small grain is to be dried, the hardware cloth should be covered with wire screening.

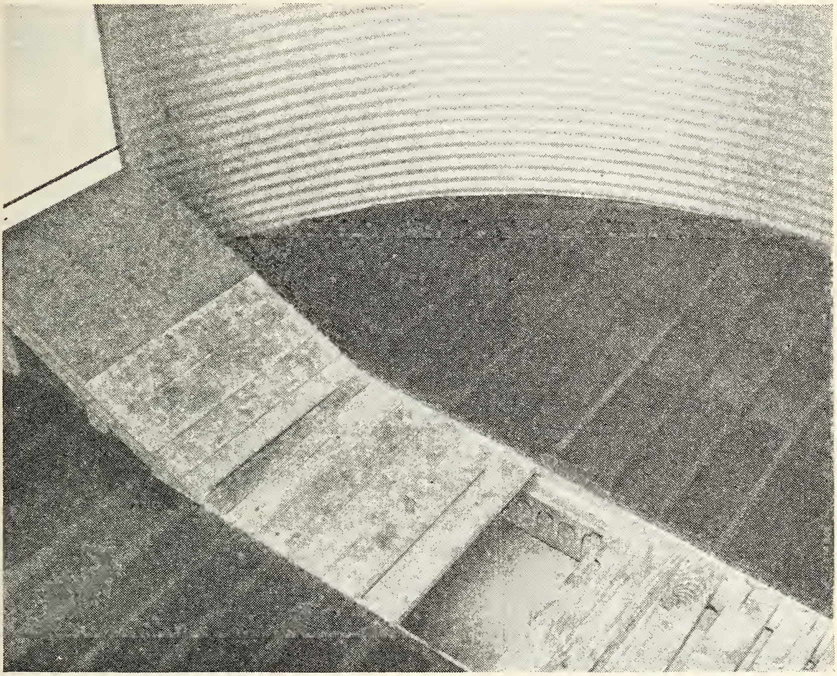

FIGURE 6.—A false floor developed for drying ear corn or shelled corn.

Several different designs of corrugated or ribbed perforated sheet-metal flooring are now on the market. When these materials are used, the wood joists can be omitted and the floor supported on 2- by 6-inch sills laid flat on rows of concrete blocks spaced from 20 to 30 inches on centers, the spacing depending upon the design of floor sheets and kind and gage of sheet metal. One concrete block is needed to support each 50 bushels of grain.

Olson, Petersen, and Yung[2a] describe a system of main and lateral

[2a] OLSON, E. A., PETERSEN, G. M., and YUNG, F. D. GRAIN DRYING WITH FORCED AIR CIRCULATION. Nebr. Univ. Ext. Cir. 736, 9 pp., illus. 1949. [Processed.]

air ducts that can be placed on the bin floor and used instead of a perforated floor for introducing air to the grain.

Drying With Unheated Air

The rate of drying ear corn with unheated air depends upon weather conditions. When air temperature is below 40° F. or when the air is very damp, drying will be so slow that operation of the fan may not be profitable. If the corn is heating, however, the fan should be operated often enough to keep the corn cool.

Ventilation should begin as soon as the crib or bin is filled. The simplest and most effective way to dry the corn rapidly is to operate the fan continuously day and night except in rain or fog. Tests of continuous ventilation have shown that a good deal of drying takes place at night if the corn has been warmed up by ventilation during the day. In the Midwest under reasonably good weather conditions in October, corn ventilated in this way has dried from 30 percent kernel moisture down to 20 percent in 10 days to 2 weeks at a power cost of 2 to 3 cents per bushel.

Some saving in power cost can be made by operating the fan only on warm clear days and only during part of each day, but it is questionable whether the saving will pay for the automatic control or the extra attention necessary. If electric power is used, the fan can be started and stopped automatically by a combined thermostat and humidistat that will cause the fan to run only when the temperature is above a set limit and the humidity below a set limit. In a test at Ames, Iowa, in the fall of 1949, automatic operation only when temperature was above 50° F. and humidity below 70 percent resulted in more drying per hour of operation but less drying per day than did continuous ventilation.

If ventilation is to be intermittent but without automatic control, the fan should be started about 10 a. m., except on rainy or foggy days, and run until the corn has cooled in the evening, about 10 p. m. A short period of operation during the warm part of the day when the corn is cold may do more harm than good.

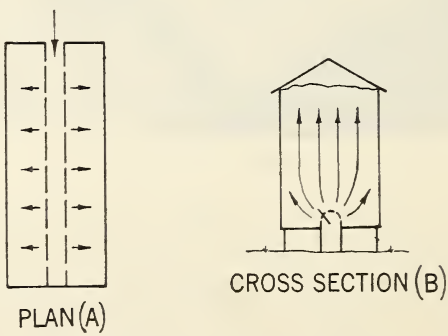

Figure 7.—Use of shelling trench for air duct. Plan (*A*) and cross section (*B*) shown. All four walls of the crib should be covered as shown by solid lines and shelling trench should be airtight at end opposite air intake. Air blown into the shelling trench moves upward to the surface of the corn. A ventilator above the shelling trench should be added as shown if an air duct larger than the shelling trench is needed.

Under good conditions the corn can be dried to 18 percent moisture in the late fall and early winter. After that, if the corn is contained in a crib, natural ventilation will be sufficient. If the corn is not dried sufficiently in the fall or if it is in a tight bin, additional fan operation will be needed as the weather warms up in the spring.

Any of the crib and duct arrangements shown in figures 1 to 13 can be used for drying with unheated air. Preparation of a crib with a shelling trench is shown in figure 7, of a frame crib with a ventilator in figure 8, and of a crib with perforated floor in figure 9. When the arrangement shown in figure 9 is used, some prefer to build the walls tight and make no use of natural ventilation. Others may prefer slatted walls that will be covered with reinforced kraft paper or with canvas only during the period of fan operation.

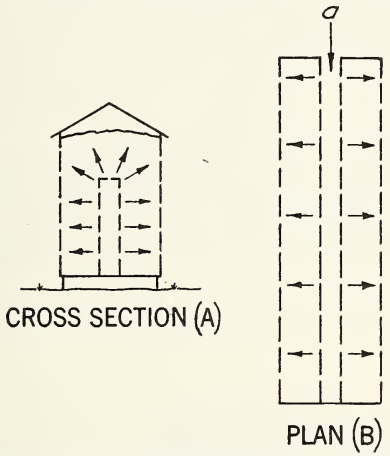

FIGURE 8.—Frame crib with ventilator, showing cross section (*A*) and plan (*B*). End walls in plan (*B*) should be covered for artificial drying but left uncovered for natural ventilation. Air blown into ventilator at *a* escapes through corn as shown by arrows.

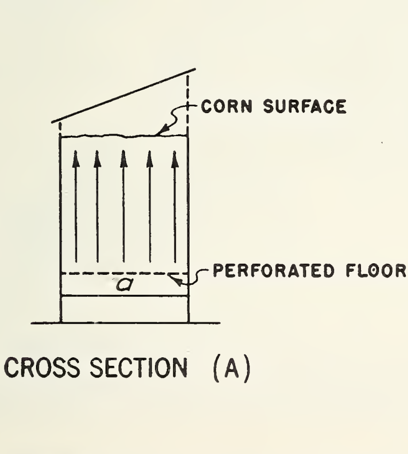

FIGURE 9.—Perforated floor and tight side walls. The four crib walls are covered with canvas or paper to depth of corn. Air blown into plenum chamber at *a* beneath false perforated floor moves upward to surface of corn.

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AMOUNT OF AIR NEEDED

Air flow of from 5 to 10 cubic feet per minute per bushel of corn is recommended. For a crib with a capacity of 1,000 bushels a fan with capacity of 5,000 to 10,000 cubic feet per minute against one-half-inch resistance pressure will be needed. A 2- or 3-horsepower motor will be required.

LIMIT OF MOISTURE

Since drying with unheated air depends upon weather conditions after the crib is filled, no definite limit can be set on how wet the corn may be when cribbed. In a humid climate the maximum permissible moisture is lower than in a dry climate. Corn with as high as 35 to 40 percent moisture has been dried by this method. However, there is risk of some spoilage of corn if the initial moisture content is 30 percent or more and if harvest is followed by a long period of cloudy weather.

COSTS

The costs of drying with unheated air will depend upon the initial cost of the fan and motor installation and the hours of operation that may be necessary. With 1,500 bushels of corn and 10,000 cubic feet per minute air flow, it would take about 540 hours fan operation with air temperature 60° F. and humidity 70 percent to dry the corn from 25 to 18 percent moisture in the kernels. On this basis, and with the initial cost of installation $400, the cost of drying may be estimated as follows:

	Dollars
Annual equipment cost (interest, depreciation, etc.)	40. 00
Electric current, 3×540=1,620 kilowatt-hours at 3 cents	48. 60
Labor of attendance, 15 hours at $1.00	15. 00
Total	103. 60

Cost per bushel: 103.60÷1500, or $0.069.

If the fan and motor can be used for other purposes also, such as drying hay and small grains, only part of the annual cost should be charged against the corn. The number of hours of fan operation varies widely with changes in weather conditions and in corn moisture content.

Drying Tests With Heated Air in Farm Cribs

In August 1947, specifications were prepared by the United States Department of Agriculture for portable driers [3] considered suitable for drying corn in farm cribs by ventilation with heated air. These specifications were used by the Department in purchasing seven portable driers for use in testing this method of curing corn. Two are direct-heat driers that burn fuel oil and discharge the burned gases directly into the air for drying (fig. 10). Two burn fuel oil in a heat exchanger or furnace that heats the drying air but discharges burned gases to outside air (figs. 11, 12, and 13). Two of the heat-exchanger

[3] The term "drier" is used in this discussion to indicate a heater and blower unit to be used for drying grain. This conforms to common usage, although "drier" is frequently used to describe a container for grain during drying or a complete drying system, including such equipment as heater, fan, ducts, grain container, and conveyors.

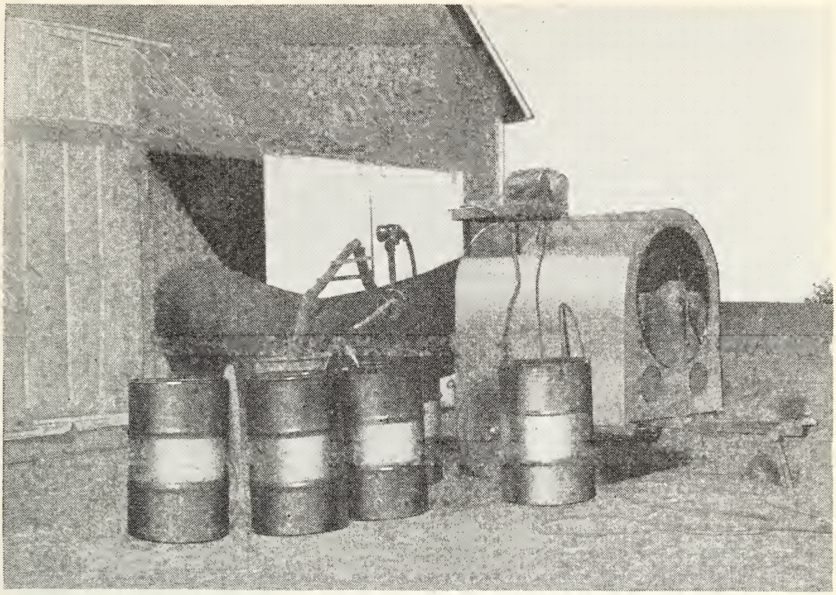

FIGURE 10.—Drying ear corn in one-half of a double crib with direct-heat, oil-burning drier. End wall of crib covered with paper to prevent short circuiting and loss of drying air. Duct arrangement as in figure 1, *B*. For safety the reserve fuel supply should be at least 50 feet from crib and drier.

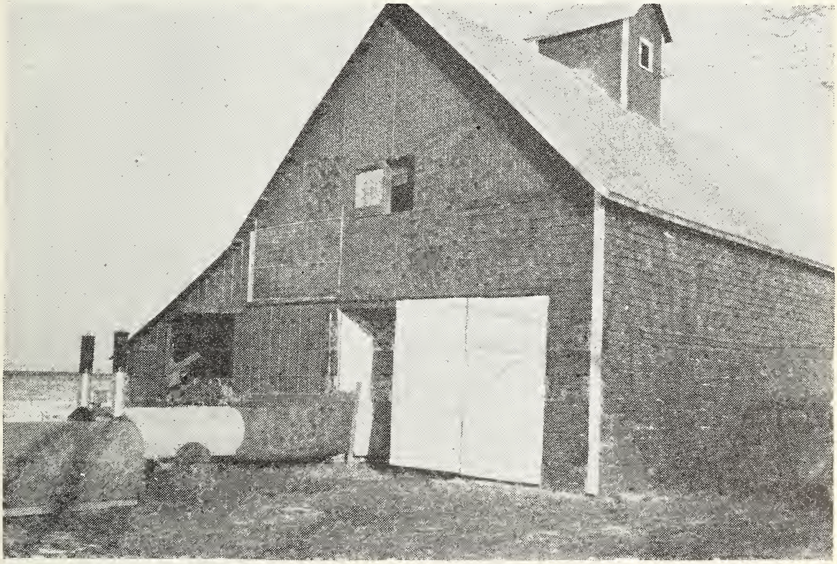

FIGURE 11.—Drying corn in double crib with overhead bins by means of oil-burning drier with heat exchanger. Canvas duct on inside wall of crib. Crib ends sealed. (See fig. 1.)

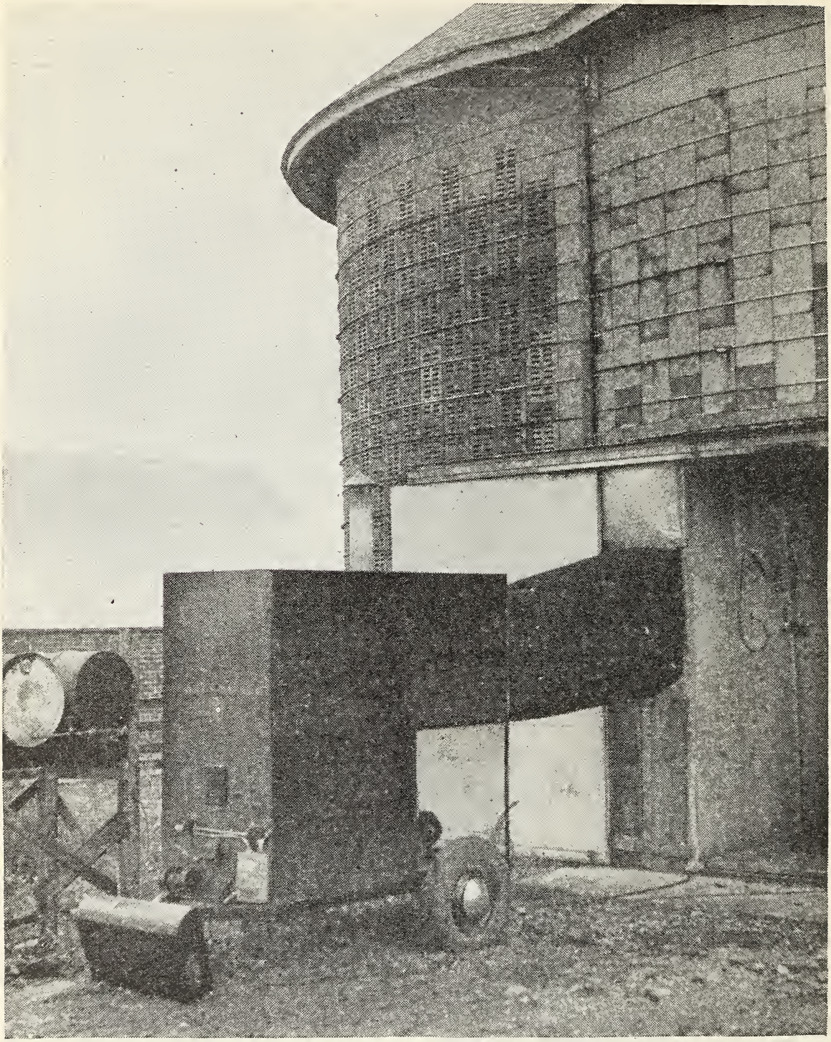

FIGURE 12.—Drying corn in curved-wall concrete crib of type shown in figure 5 with oil-burning drier with heat exchanger. Main duct is of reinforced paper and 2 by 4 framing. Preparation for drying is a modification of method used in plan (*C*), figure 1.

type burn coal or other solid fuels, and one of the direct-heat type burns propane. These driers and several models lent by manufacturers were used in tests on farms in areas where corn with high moisture content was cribbed. The number and location of these tests by States are recorded in table 1.

TABLE 1.—*Tests for drying ear corn in farm cribs, 1947–48*

State	Tests	Estimated bushels dried
	Number	*Number*
Iowa	2	500
Illinois	51	71, 000
Indiana	22	28, 000
Ohio	8	5, 000
Michigan	3	1, 300
Total	86	105, 800

The moisture in the corn kernels before drying in the different tests ranged from somewhat under 20 percent to as much as 30 percent. In most cases it was between 22 and 26 percent. In nearly all these cribs, severe mold damage would have occurred if the corn had been held in storage until summer without drying.

FIGURE 13.—Drying corn in crib with vertical duct or ventilator through center by means of oil-burning drier with heat exchanger. (See fig. 8.)

COSTS

Large quantities of water must be removed to dry ear corn that is too moist for ordinary crib storage. The costs of drying will be largely dependent on the amount of water removed. The approximate quantity of water contained in ear corn and the different percentages of moisture in the kernels [4] is shown in table 2. These data are based on cob and kernel moisture when the corn is harvested. In crib storage during the winter, the cobs dry somewhat faster than the kernels, and therefore after 2 to 4 months of storage, the total water in the ear for a given kernel moisture content will be somewhat lower than stated in the table.

TABLE 2.—*Approximate quantity of water in ear corn with different percentages of moisture in the kernels when harvested*

Kernel moisture content	Water contained in bushel [1] of ear corn		
	In kernels	In cobs	Total
Percent, wet basis	*Pounds*	*Pounds*	*Pounds*
30	20. 3	9. 9	30. 2
29	19. 3	9. 3	28. 6
28	18. 4	8. 7	27. 1
27	17. 5	8. 2	25. 7
26	16. 6	7. 7	24. 3
25	15. 7	7. 2	22. 9
24	14. 9	6. 6	21. 5
23	14. 1	6. 1	20. 2
22	13. 3	5. 6	18. 9
21	12. 5	5. 1	17. 6
20	11. 8	4. 5	16. 3
19	11. 1	3. 9	15. 0
18	10. 4	3. 3	13. 7
17	9. 7	2. 7	12. 4
16	9. 0	2. 2	11. 2
15	8. 3	1. 8	10. 1
14	7. 6	1. 5	9. 1
13	7. 0	1. 2	8. 2
12	6. 4	. 9	7. 3
11	5. 8	. 6	6. 4
10	5. 3	. 4	5. 7

[1] Bushel is defined here as the quantity of ear corn required to yield 56 pounds of shelled corn at 15.5 percent moisture. With this definition of the bushel, the figures given in the second column for water in the kernels are obtained by arithmetical calculation and are exact. The figures in the third column for water in the cobs are estimates based on a large number of observations of cob-kernel moisture relations and cob-kernel weights of good quality corn. The weight of water in the cobs will vary considerably with different kinds of corn and after different periods of crib storage.

The quantity of water removed from each bushel in drying may be obtained from the table by subtracting the total water content at the

[4] SCHMIDT, J. L. HOW TO REDUCE EAR CORN TO BUSHELS OF SHELLED CORN. Agr. Engin. 29: 294–296, illus. 1948.

final kernel moisture percentage from the total water content at the initial kernel moisture percentage. For example, to dry ear corn from 25 to 17 percent moisture in the kernels, about 10.5 pounds of water must be removed from each bushel of corn. For this amount of drying, with fuel oil at 15 cents per gallon, test results showed that the cost for fuel was generally between 4 and 6 cents per bushel. Figured at 3 cents per horsepower-hour, the cost of power to drive the drier fan amounted to about one-half cent per bushel. Other costs, such as labor, interest, depreciation, and insurance, may run the cost up to about 10 cents per bushel.

As an example, in test number Ohio–3, made in cold weather, the amount of corn used was 795 bushels; kernel moisture before drying was 24.1 percent and after drying, 11.8 percent; the drier burned 6.8 gallons of No. 3 fuel oil per hour and delivered 8,300 cubic feet per minute of air, using a 3-horsepower electric motor; average outside air temperature was 9.2° F. and air was heated to 119.1°. Costs were estimated as follows:

	Dollars
No. 3 fuel oil, 315 gallons at 15 cents	47. 25
Motor operated 49.2 hours—estimate 148 kilowatt-hours at 3 cents	4. 44
Labor, 6 hours fixing duct to crib and 25 hours attending drier (one-half of operating time), total, 31 hours at $1 per hour	31. 00
Cost of owning drier (interest, depreciation, repairs, etc., estimated at $100 per year; time used, 500 hours per year) 49.2 hours at 20 cents	9. 84
Insurance	(1)
Total	92. 53

Cost per bushel:[1] 92.53÷795, or $0.116.

[1] The cost of insurance is not included because a good estimate cannot be given. Some insurance companies have charged an extra premium of $1.00 per $100 valuation to cover fire hazard due to use of a drier. Others have given farmers this extra coverage without any additional premium.

Since the corn in this test was dried to a lower moisture content than is necessary for crib storage, there was an increase in cost of drying. The cost per bushel would have been somewhat lower if drying had been done in warmer weather and if the crib had held 1,200 to 1,500 bushels, as the larger amount would have resulted in lower unit-labor costs.

DAMAGE TO CORN DURING DRYING

In the 86 drying tests there were a few cases in which slight mold damage was observed in pockets where air flow was restricted. Direct-heat driers, that is, oil burners that mixed burned gases with the drying air, did not impart any objectionable odor to the corn. In a few tests, because of imperfect burner adjustment, a light film of soot was deposited on one side of ears exposed to the air duct. This condition is not known to be harmful and only an extremely small fraction of the corn in the crib was affected. It was impossible to detect any damage due to soot after the corn was shelled.

BENEFITS OBTAINED BY DRYING

Most of the farmers who cooperated in the 1947–48 drying tests wanted to store the corn for summer feed. Drying for this purpose

was uniformly successful and made the difference between good quality and badly molded feed. The only exceptions were the minor damages previously explained that were due to conditions that can be avoided without difficulty.

When the cooperator sold the corn, drying enabled him to avoid the price discount for high moisture. In a few cases sour or musty odors were present and the corn was brought to normal odor by drying. The net benefit after paying the cost of drying was generally between 10 and 50 cents per bushel. The profit will depend, of course, upon the market-price discount for high moisture, which varies with market and weather conditions.

General Specifications for a Portable Heated-Air Drier

For the purpose of illustrating the general requirements of a drier of this type the following specifications are suggested for an oil-burning drier suitable for drying 300 to 1,500 bushels of ear corn at a time. Publication of these specifications is not intended to discredit any drier that does not comply with them, provided it has Underwriters Laboratory approval.

General description.—The drier shall consist of an oil-burning heater for heating the air to be used for drying, a fan with belt pulley, an electric motor or a gasoline engine for operating the fan, necessary safety controls and protective devices, and a flexible duct for connecting the drier to the air duct of the crib or other structure in which the grain is to be dried. All component parts of the drier are to be assembled to form a complete portable drying unit mounted on a pneumatic-tired trailer for convenient movement of the drier from one building to another or on the highway.

Fan.—The fan shall have capacity to deliver to the crib at least 9,000 cubic feet per minute of drying air against a static pressure of ½-inch water column, this pressure to be in addition to the pressure drop through the drier. If the drier is to be used for drying shelled corn or small grains, as well as ear corn, the fan shall also have capacity to deliver at least 4,000 cubic feet per minute against 1½ inches static pressure in addition to the pressure drop through the drier. The power requirement to drive the fan shall not exceed 3 brake horsepower at the above-stated air deliveries and static pressures.

Electric motor.—If the fan is to be driven by an electric motor, the electric motor shall be a 3-horsepower single-phase, 60-cycle, 220-volt, repulsion-start, induction-run or capacitor type with a magnetic starter switch and a thermal overload cut-off switch. The electric motor shall be connected to the fan by means of a V-belt drive.

Gasoline engine.—If the fan is to be driven by a gasoline engine, the engine shall have capacity to deliver at least 3 brake horsepower to the fan continuously under all weather conditions without overheating and without excessive wear or depreciation. It shall be designed to start without difficulty in cold weather. It shall be well balanced to prevent excessive vibration when it is mounted on light framework of the drier. It shall be four stroke cycle, automatic-throttle governed, with efficient oiling, cooling, carburetion, ignition, and air-cleaning systems. The engine shall be connected to the fan by V-belt drive. It is preferred that the engine shall be housed so that air that has been used to cool it will be drawn through the drier fan, thus utilizing engine heat for heating the drying air.

Heating unit.—The heating unit shall be provided with a pressure-atomizing-type burner designed to burn domestic furnace fuel oil. The fuel pump shall be provided with safe and convenient flexible tubing for drawing fuel from a standard 55-gallon drum or other supply tank set near the drier. A sediment bulb and strainer shall be provided in the fuel line between supply tank and burner. The fuel pump and all fuel lines shall be located outside of the drying air stream and away from the combustion chamber to avoid any unnecessary fire hazard. The heating unit shall have capacity to add 780,000 British thermal units of sensible

heat per hour to the air passing through the drier. This is enough heat to raise the air temperature 70° F. when the fan is delivering 9,000 cubic feet per minute. The burner shall be adjustable to approximately 50 percent, 75 percent, and 100 percent of the above-specified capacity. *A*, Direct-heat drier: The heating unit shall have a maximum fuel rate of 6 to 6½ gallons of fuel oil per hour. At all rates of fuel consumption, the percent of carbon monoxide by volume in the drying air shall not exceed one-hundredth of one (0.01) percent and the drying air shall be free of objectionable odors that would affect the quality of the grain. *B*, Heat-exchanger-type drier: If the drier is of the heat-exchanger type, the heat exchanger shall be designed to transfer to the drying air at least 65 percent of the heat developed by burning fuel and the heater shall be an atomizing type of fuel oil burner with a maximum fuel rate of 8 to 10 gallons of fuel oil per hour.

The burner ignition shall be by electric spark that must be hot enough to ignite the flame in zero weather.

***Safety.*—The drier shall be provided with controls and protective devices as follows:**

1. An automatic control to shut down the entire drier in case of flame failure or material reduction in heat due to a partially clogged fuel nozzle or other maladjustment of the burner. This control shall be adjustable to permit operation of the fan without operating the heater.

2. A temperature-limit control in the drying air stream that will shut down the entire drier in case of overheating of the air due either to external fire or to restriction or failure of the air flow.

3. The above controls shall be electrically operated and shall be such that in case of interruption of current to the controls, the drier will be shut down and will not start again automatically.

4. If the fan is driven by a gasoline engine, the above controls shall not be dependent upon connection to any power line. To supply electric current for the controls, a suitable generator driven by the gasoline engine shall be furnished installed with all necessary wiring and accessories.

5. If an electric motor is used to drive the fan, current from the power line shall pass through a suitable fuse box on the drier. A convenient outlet shall be provided for plugging in an extension light.

6. All air entering the drier shall pass through a screen with openings not more than one-half inch in diameter. Air entering the burner shall pass through a screen with openings not more than one-twelfth inch in diameter.

Recommendations for Drying by Forced Ventilation With Heated Air

Drying ear corn in farm cribs by forced ventilation with heated air can be done most economically by means of a portable drier mounted on a rubber-tired trailer for convenient transportation from crib to crib and from farm to farm. In this way one drier can be used to dry several cribs of corn and the equipment cost per bushel will be correspondingly lower than when a stationary drier is installed at a crib.

Drying can be done more economically in mild fall weather than in cold winter weather, but when necessary the drier can be operated throughout the winter and early spring months.

The drier may be designed to burn fuel oil, propane gas, or coal or other solid fuels. Fuel oil or gas burners may discharge burned gases into the drying air (direct heat) or they may be provided with a heat exchanger or furnace for heating the drying air and discharging burned gases through a smokestack. When a heat exchanger is used, from 25 to 35 percent of the heat value of the fuel goes up the smokestack. Various amounts of heat may be applied to the drying air. In mild weather, it may be desirable in some cases to heat the air only 10 to 20 degrees above atmospheric temperature. Drying will be faster (but not necessarily more economical) at higher temperatures. An upper limit of 130° F. for the drying air is recommended when the

corn is to be used for livestock feed or for milling. Temperatures higher than 130° will increase the fire hazard and damage the corn for wet milling (production of starch, syrup, oil, etc.). Drying temperatures of 110° or lower are used for drying seed corn.

The estimated drying time and fuel consumption for batches of different sizes when a drier as specified above is operated at full capacity are recorded in tables 3 and 4. With a small batch of corn, for example, 200 bushels, the air flow is at a rate of $\frac{9{,}000}{200}=45$ cubic feet per minute per bushel. At this rate of flow, the air does not stay in the crib long enough to pick up its full load of moisture, consequently the fuel consumed per 1,000 bushels will be large. (See last column, tables 3 and 4.) For drying a batch of less than 600 bushels, better fuel economy will be obtained by adjusting the drier for a lower rate of fuel consumption and lower rate of air flow.

Table 3.—*Estimated drying time and fuel consumption for drying ear corn, kernel moisture before drying, 25 percent wet basis; temperature rise 70° F.*

[Conditions: Direct-heat drier; fuel-oil consumption, 6 gallons per hour; air flow, 9,000 cubic feet per minute; temperature rise, 70° F.; atmospheric temperature, 50°; relative humidity, 70 percent; kernel moisture of ear corn before drying, 25 percent wet basis—dried to 18 percent in the wettest layer in the batch]

Size of batch	Estimated drying time	Estimated fuel consumed	Final average kernel moisture	Drying time per 1,000 bushels	Fuel consumed per 1,000 bushels
Bushels [1]	*Hours*	*Gallons*	*Percent*	*Hours*	*Gallons*
200	16.5	99	15.8	82.5	495
400	25.0	150	14.2	62.5	375
600	36.0	216	12.7	60.0	360
800	47.0	282	10.2	59.0	355
1,000	58.0	348	9.7	58.0	350
1,200	69.0	414	9.2	58.0	350
1,400	81.0	492	8.4	58.0	350
1,600	93.0	558	8.0	58.0	350
1,800	104.0	630	7.6	58.0	350
2,000	116.0	708	7.2	58.0	350

[1] 1 bushel of ear corn is defined here as the quantity required to yield 56 pounds of shelled corn at 15.5 percent moisture.

Good fuel economy is obtained by drying in large batches. The limit in size of batch should be determined by the total drying time. Generally, when the temperature of drying air is above 90° F., the drying time should not exceed 100 hours, because in a longer period there may be some molding of corn in the parts of the crib where the corn dries last (where the air leaves the crib). On this basis, if the corn is very wet (30 percent moisture in the kernels) no more than 1,200 bushels should be dried at a time under the conditions stated in table 4. If the initial corn moisture content is 25 percent, under conditions stated in table 3, up to 1,800 bushels may be dried at a time.

If the outside air temperature is 30° F. instead of 50°, the drying time will be about one-fourth to one-third longer; but with the same temperature rise, 70°, temperatures in the crib will be less favorable to mold growth.

TABLE 4.—*Estimated drying time and fuel consumption for drying ear corn, kernel moisture before drying, 30 percent wet basis; temperature rise 70° F.*

[Conditions (same as in table 3 except initial corn moisture content): Direct heat drier; fuel-oil consumption, 6 gallons per hour; air flow, 9,000 cubic feet per minute; temperature rise, 70° F.; atmospheric temperature, 50°; relative humidity, 70 percent; kernel moisture of ear corn before drying, 30 percent wet basis—dried to 18 percent in the wettest layer in the batch]

Size of batch	Estimated drying time	Estimated fuel consumed	Final average kernel moisture	Drying time per 1,000 bushels	Fuel consumed per 1,000 bushels
Bushels [1]	*Hours*	*Gallons*	*Percent*	*Hours*	*Gallons*
200	23	138	15.3	115	690
400	38	228	13.0	95	570
600	53	318	10.2	88	530
800	70	420	9.3	87	525
1,000	85	510	8.3	85	510
1,200	100	600	8.2	84	505
1,400	117	702	8.2	84	505
1,600	133	798	8.0	83	500
1,800	150	900	8.0	83	500
2,000	166	996	7.8	83	500

[1] 1 bushel of ear corn is defined here as the quantity required to yield 56 pounds of shelled corn at 15.5 percent moisture.

Although all batches are dried to an estimated final moisture content of 18 percent in the wettest layer, the final average moisture content of the batch is lower than 18 percent and is much lower in the large batches than in the small ones (tables 3 and 4). Under the conditions stated in the tables, the corn near the air entrance to the crib dries first and, unless the drying period is short, may dry to 5 or 6 percent moisture before corn near the air exit begins to dry. The longer the period of drying, the farther into the crib this area of overdried corn will extend.

For safe crib storage of corn after drying in late fall and winter, the wettest layer should be dried to 18 or 20 percent moisture. The corn that has been overdried will regain moisture from the air during crib storage. If the corn is to be shelled and sold at once, drying should be stopped before the average moisture content of the batch is below the moisture limit for the grade of corn.

Under some conditions it may be desirable to dry ear corn at lower temperatures than assumed in calculating tables 3 and 4. Estimates based on the same conditions as in table 4 except a 20-degree instead of a 70-degree temperature rise are recorded in table 5. By comparing tables 4 and 5, it will be noted that, with the lower temperature rise, 20°, the drying time is much longer but the final moisture content is more nearly uniform. With batches of 800 bushels or more the fuel consumption per 1,000 bushels is less with the low temperature rise. With a 20-degree rise, making the temperature of drying air 70° (table 5), the total drying time may be as much as 300 hours without appreciable mold damage, because molds grow slowly under this condition.

Table 5.—*Estimated drying time and fuel consumption for drying ear corn, kernel moisture before drying, 30 percent wet basis; temperature rise 20° F.*

[Conditions (same as in table 4 except temperature rise): Direct heat drier; fuel oil consumption, 1.7 gallons per hour; air flow, 9,000 cubic feet per minute; temperature rise, 20° F.: atmospheric temperature, 50°; relative humidity, 70 percent; kernel moisture of ear corn before drying, 30 percent wet basis—dried to 18 percent kernel moisture in wettest layer in the batch]

Size of batch	Estimated drying time	Estimated fuel consumed	Final average kernel moisture	Drying time per 1,000 bushels	Fuel consumed per 1,000 bushels
Bushels [1]	*Hours*	*Gallons*	*Percent*	*Hours*	*Gallons*
200	140	238	17.0	700	1,190
400	170	290	16.4	425	725
600	200	340	15.8	335	570
800	235	395	15.3	290	495
1,000	270	465	14.7	270	465
1,200	310	525	13.9	260	440
1,400	350	595	13.0	250	425
1,600	390	665	12.3	245	415
1,800	435	730	11.8	242	405
2,000	475	810	11.5	238	405

[1] 1 bushel of ear corn is defined here as the quantity required to yield 56 pounds of shelled corn at 15.5 percent moisture.

Methods of Drying Compared

Drying with unheated air is dependent upon weather conditions. Intermittent fan operation may be necessary for a few weeks after harvest and for a similar period in the early spring. One fan and motor should not be depended upon to dry more than one crib of corn per year. The advantages of drying with unheated air are that there is no expense for fuel and there are no fire hazards caused by the operation of a heater.

Drying a crib with heated air usually will be completed within 2 to 4 days. After being dried, the corn can be stored in the crib without further attention. It will be dry enough to grind readily and to store as ground feed for reasonable periods of time. One drier can be used to dry several cribs of corn. This method can be carried on regardless of weather conditions, but the cost will be lower in mild fall weather than in the winter.

The total cost of drying is not likely to differ widely in these two methods, but it may be somewhat higher with heated air, as indicated by the cost examples given on previous pages. These examples are based on different and not entirely comparable situations and serve to illustrate the method of estimating the costs for various sets of conditions.

DRYING SHELLED CORN

The essential differences between drying shelled corn and drying ear corn are:

1. The power required to force air through shelled corn stored in a bin is much greater than for ear corn.

2. A large quantity of water is contained in the cobs of high-moisture ear corn. (See table 2.) The necessary evaporation of a large part of this cob moisture is avoided if the corn is shelled before drying. Shelled corn, however, must be dried to 12 or 13 percent moisture for safe storage through the summer, whereas ear corn may be stored safely in a crib for a full year if dried to 18 or 20 percent moisture in the fall or winter. The amount of moisture to be removed is generally less in drying shelled corn than in drying ear corn, and this advantage may offset or more than offset the additional cost of power for blowing air through shelled corn.

3. Shelled corn can be dried in a continuous-flow drier, whereas it is extremely difficult to get ear corn to flow smoothly.

Shelled corn can be dried in a continuous-flow drier such as used by some elevators or in a batch drier, as, for example, when the grain is dried in a bin (fig. 14). Continuous-flow driers have been developed for drying rice on farms, but have not been used very extensively for drying corn or other grains on farms in the Midwestern States.

Bin-Drying Tests

A good many experiments have been run by Purdue University on drying shelled corn in bins provided with perforated floors, as shown in figure 9. The data in table 6 are from a report of the Agricultural Engineering Department of that university. On both the farms covered by the data in table 6 (Frankfort and Noblesville, Ind.) the drying was done in overhead bins that were equipped with ventilated floors supported above the regular floor, and indirectly fired driers (with heat exchangers) were used. In order to reach the overhead bins and yet have the drier set outside the building, a long canvas duct had to be used. This use resulted in loss of both air and heat, and consequently there was some increase in cost of drying. The batch-drier tests reported in table 6 were made with the drying air heated to 10° to 25° F. warmer than the atmosphere.

In a drying test at Ames, Iowa, about 800 bushels 4 feet deep were dried in a bin at a drying temperature of about 105° to 110° F. and an atmospheric temperature varying between 30° and 60° F. The shelled corn was dried from an average initial miosture of 17.8 percent to an average final moisture of 12.1 percent. After drying, the moisture ranged from 9.0 to 16.6 percent. After the corn was transferred to another bin the next day, the moisture range was from 10.3 to 15.0 percent. It took 18 hours with heat and about 6 hours of fan operation after the heater was shut off to accomplish the drying. One hundred gallons of fuel oil were used in the heat-exchange drier and the air pressure under the grain was about 1.5 inches.

TABLE 6.—*Data on shelled-corn drying tests* [1] *in farm-type bins*

Date	Quantity of corn	Depth of corn	Moisture content of corn		Drying time	Consumption		Cost		
			Initial	Final		Fuel	Power	Fuel	Power	Per bushel
1,000-BUSHEL EXPERIMENTAL STEEL BIN, PURDUE UNIVERSITY										
1946	*Bushels*	*Feet*	*Percent*	*Percent*	*Days*	*Gallons per bushel*	*Kilowatt-hours per bushel*	*Dollars*	*Dollars*	*Cents*
Nov. 15	480	4. 5	26. 6	13. 5	5	0. 25	0. 76	16. 80	8. 75	5. 3
26	800	6. 8	24. 0	12. 2	7	. 23	. 70	25. 80	15. 81	5. 2
FARM BIN, NOBLESVILLE, IND.										
1947										
May to July	480	4. 5	15. 6	13. 0	3	0. 11	0. 42	8. 10	4. 04	2. 5
	430	4. 0	16. 0	10. 9	3	. 14	. 45	8. 10	3. 86	2. 8
	780	7. 5	15. 4	10. 0	5	. 21	. 42	30. 90	18. 00	6. 3
	730	7. 0	15. 4	9. 1	3	. 16	. 28	18. 00	4. 08	3. 0
	832	8. 0	15. 4	11. 5	3½	. 07	. 54	8. 40	10. 00	2. 2

FARM BIN, FRANKFORT, IND.

1948										
Mar. 11	625	7. 8	22. 1	11. 7	7	0. 70	1. 39	70. 63	14. 50	13. 6
19	1, 510	8. 0	23. 4	11. 8	10	. 30	. 75	73. 71	18. 80	6. 1
29	1, 320	7. 0	20. 1	11. 0	7	. 26	. 62	56. 21	13. 79	5. 3
Apr. 5	520	6. 5	18. 1	11. 8	5	. 32	1. 08	26. 70	9. 35	6. 9

2,740-BUSHEL STEEL BIN, FORESMAN SWITCH, IND.

1948										
Mar. 16	1, 727	10. 0	24. 5	11. 0	10	0. 13	2. 04	44. 27	70. 54	6. 6

[1] Drying air heated to 10° to 25° F. above atmospheric temperature.

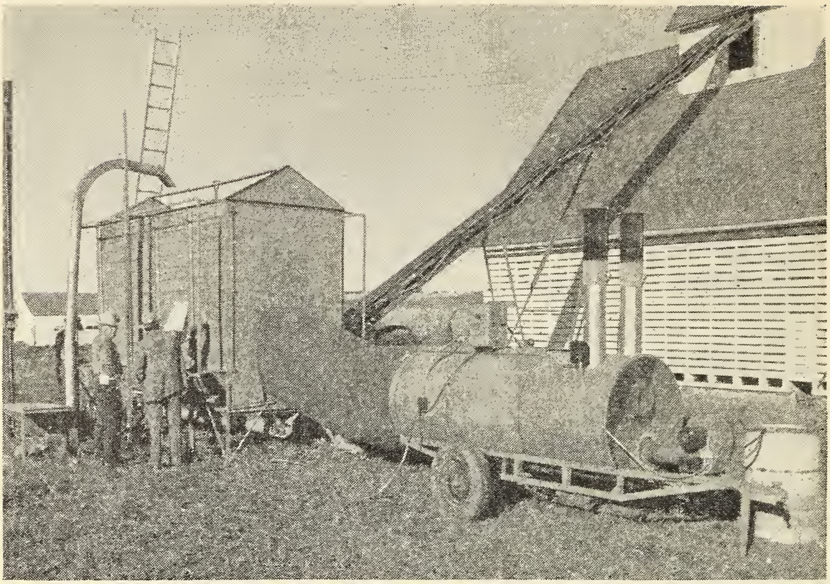

FIGURE 14.—An experimental vertical-column batch drier for small grain or shelled corn. Batches of about 125 bushels of grain are dried, then transferred to storage bin.

DRYING TEMPERATURE

Whether a batch or a continuous drier is used, the rate of drying is increased by higher temperatures. In a bin drier the bottom layers dry first and the top last, the difference in amount and rate of drying depending on the humidity, temperature, and volume of drying air. When the drying air is heated to between 10° and 25° F. above atmospheric temperature, the relative humidity of the heated air will usually be between 30 and 60 percent. In this range none of the corn will be dried below about 10 to 12 percent moisture. Drying will be slow, especially in cold weather, but eventually all the corn can be dried to a relatively uniform moisture of 10 to 12 percent.

If the drying air is heated to 70° F. above atmospheric temperature, the bottom layers of grain will be dried to as low as 5 or 6 percent moisture, possibly before the upper layers dry at all. The drying will progress upward and eventually all the corn can be dried to a uniform moisture content of 5 to 6 percent. Usually, grain for short-time winter storage should be dried to 16 percent average moisture content and that for storage into warm weather to 12 or 13 percent. The bottom layer of grain may then have dried to 5 or 6 percent moisture while the top layer may have dried very little.

Continued ventilation of the corn after the heater is shut off will partially equalize the moisture content in the various layers, but the top layers may still be too wet for safe storage. Unless the storage period is to be short, grain that has been dried with a temperature rise of more than 25° F. should be mixed by moving it to another bin.

The advantage of the low temperature rise is the resulting uniform moisture that will make the grain safe for storage without mixing. The advantages of using a higher temperature rise are that the drying can be completed in a shorter time and the total power cost for driving the air through the grain will be less.

Comparison of shelled corn bin-dried under various conditions from an initial moisture content of 20 percent to an average moisture of 13 percent may be made from data in table 7.

TABLE 7.—*Drying time, amount of heat required, and final range in moisture content as computed for bin drying of shelled corn from 20 percent initial moisture to average of 13 percent final moisture under two atmospheric conditions, two rates of airflow, and two temperature rises*

Drying-air temperature	Air flow, 4 cubic feet of air per minute per bushel			Air flow, 10 cubic feet of air per minute per bushel		
	Drying time	Heat required	Final moisture range	Drying time	Heat required	Final moisture range
	Hours	*B. t. u.*[1] *per bushel*	*Percent*	*Hours*	*B. t. u.*[1] *per bushel*	*Percent*
ATMOSPHERIC TEMPERATURE 30° F; RELATIVE HUMIDITY 70 PERCENT						
50° F. (20° rise)	116	10, 750	9. 0–19. 0	52	12, 100	11. 5–16. 7
100° F. (70° rise)	31	9, 920	4. 7–20. 0	13	10, 600	7. 0–18. 2
ATMOSPHERIC TEMPERATURE 50° F; RELATIVE HUMIDITY 70 PERCENT						
70° F. (20° rise)	81	7, 210	9. 2–19. 7	38	8, 400	10. 4–16. 7
120° F. (70° rise)	26	8, 070	5. 0–20. 0	11	8, 100	6. 2–19. 7

[1] British thermal units per bushel of corn. One B. t. u. is amount of heat required to raise temperature of 1 pound of water 1° F.

DEPTH OF CORN AND RATE OF AIR FLOW

Drying has been done in a bin with as much as a 10-foot depth of shelled corn. No doubt even greater depths could be dried. Since the cost of power for operating the fan goes up greatly as the depth increases, it will usually be most economical to dry a depth of not over 4 to 6 feet.

If it is desired to use the same heated-air drier interchangeably for ear and shelled corn, the unit described in the specifications on pages 16 and 17 for ear corn can be used satisfactorily for shelled corn. The full capacity of the burner, however, will probably not be needed. In cold or moderate weather, the air can be heated about 70° F. as for ear corn; but since the resistance to air flow is likely to be greater than for ear corn, less air will be delivered and the fuel rate of the burner will need to be reduced.

The resistance to air flow in shelled corn depends greatly on the depth of the corn. How the pressure is increased by increasing the depth and by increasing the volume of air per minute per bushel of corn is shown in table 8.

TABLE 8.—*Pressure (inches of water) required to force air through shelled corn*

Depth of corn	For supplying 4 cubic feet per minute per bushel		For supplying 10 cubic feet per minute per bushel	
	Pressure required	Power required per 1,000 bushels	Pressure required	Power required per 1,000 bushels
Feet	*Inches*	*Horsepower*	*Inches*	*Horsepower*
2	0. 045	¾	0. 20	2
4	. 40	1	1. 6	4
8	2. 3	3	9. 0	27

Since the power required varies with the pressure and volume of air, it is obviously uneconomical to use high volumes of air through deep layers. There is no definite upper limit of pressure or depth, but generally if the pressure required is over 2 or 3 inches the power requirement is likely to be excessive.

As indicated in tables 7 and 8, the choice of an optimum rate of air flow depends on which factors are most important to the operator. In general, higher rates of air flow shorten the drying time, increase the total fuel requirement, and improve the uniformity of drying. In the examples in table 7 the drying time is reduced to less than half by increasing the rate of air flow from 4 to 10 cubic feet per minute per bushel, and the total fuel requirement is increased only slightly. At the same time, higher rates of air flow increase the requirement for fan power. In most cases, drying will be done economically by air flow of 4 to 10 cubic feet per minute per bushel.

SAFETY PRECAUTIONS

There is a fire hazard in burning fuel to heat air for drying corn. Inasmuch as this hazard is present all the farm buildings may be jeopardized; but the hazard can be reduced by well-designed equipment kept in good adjustment and by drying the corn in a steel bin as illustrated in figures 6 and 14. The owner of the grain and building should make sure that fire risk due to operation of the drier is covered by his insurance. Reserve drums of fuel should be kept at least 50 feet away from the drier and brought up only as needed. Each drier should be equipped with a hand fire extinguisher of the dry chemical or carbon dioxide type, and all electrical equipment and metal parts of the drier should be grounded.

U. S. GOVERNMENT PRINTING OFFICE: 1950